CHANGES IN INFRASPINATUS CROSS-SECTIONAL AREA AND ECHO INTENSITY IN RELATION TO SCAPULAR DYSKINESIS AND OVERHEAD TRAINING VOLUME IN COLLEGIATE VOLLEYBALL PLAYERS

Kimberly Chase

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Approved by:

D. Padua

T. Blackburn

L. Stanley

ABSTRACT

Kimberly Chase: Changes in Infraspinatus Cross-Sectional Area and Echo Intensity in Relation to Scapular Dyskinesis and Overhead Training Volume in Collegiate Volleyball Players
(Under the Direction of Darin Padua)

During the pre-season injury risk in volleyball is highest at 6.1 injuries/1000 exposures. Injury to the posterior shoulder, specifically the infraspinatus, has been attributed to repetitive eccentric loading. The high volume of overhead activity in the collegiate volleyball player has been identified is a risk factor for upper extremity injury. Cross sectional area and echo intensity of the infraspinatus muscle were assessed using diagnostic ultrasound to measure muscle damage. Visual observation of scapular dyskinesis was completed at baseline and 24 hours following the pre-season training period to assess changes due to pre-season training volume. Correlations between cross sectional area, echo intensity, scapular dyskinesis, and swing count were also examined to assess relationships between these variables. Acceptable reliability was established for all measurements. This study found no significant outcomes in cross sectional area or echo intensity, in the severity of scapular dyskinesis, or in relationships between the variables of interest.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: INTRODUCTION

The shoulder is the third mostly commonly injured area of the body, following only the ankle and knee, in the sport of volleyball.[1-5] Additionally, overuse injury at the shoulder occurs most frequently among all body regions in the sport.[1-5] The incidence of injury in volleyball athletes at the collegiate level is highest during the preseason with overall injury rate of 6.5 per 1000 athlete exposures.[4] The high incidence of injury during the preseason is likely due to the high volume of training completed by the athletes during a relatively short period of time, as teams often have multiple training sessions in a day during this phase of the season. The pre-season for collegiate volleyball occurs in the late summer when athletes are returning to school from home and conditioning levels are varied. The high volume of overhead training during the pre-season places significant stress on the glenohumeral joint and surrounding musculature. The repetitive overhead motions necessary to successfully compete in volleyball, can lead to tissue damage, pain, and injury.[6-8] The literature has shown that volleyball athletes typically experience their first injury earlier in the season, compared to other sports where injury tends to occur during the later portions of the season.[9]

Overuse is the most common mechanism of shoulder injury in volleyball as overhead swings are made during both the attacking swing and the serve.[1,3,5,6,10-14] The volume of swings is often dependent on the athlete's playing position as well as average playing time during practice and competition.[6] More than 40,000 swings by a single athlete has been observed during a single volleyball season.[11] Epidemiological reports show that outside hitters suffer the most injuries (38.7%) for all positions, followed by middle blockers (27.4%), liberos (12.0 %), setters (10.9

%) and opposite/diagonal players (7.5%). These numbers correlate well with the amount of overhead swings taken by players in these positions.[1]

Eccentric overload and repetitive stresses placed on the rotator cuff musculature and posterior joint capsule during serving and spiking, are believed to be the main causes of overuse injuries at the shoulder.[1,3,6,10,11,15,16] During the overhead spiking motion, the infraspinatus and teres minor muscles contract eccentrically to prevent anterior translation of the humerus during the acceleration phase of the swing. [17]As the volume of swings increases, these muscles fatigue and may experience intra-muscular damage, including muscular edema, micro-tearing, and a subsequent increase in cross-sectional area of the muscle.[16,18-20] Without sufficient recovery time, muscle damage can develop from overuse of the shoulder musculature. Damage to the infraspinatus can be measured through diagnostic ultrasound, which is used to determine cross-sectional area (CSA) and echo intensity (EI) to identify edema and muscle damage.[18,20-22] Persistent increased CSA due to damage and inflammation has the potential to create degeneration and failure of the tendon.[20,21]

The infraspinatus was chosen as a marker of muscle damage due to its critical role in providing stabilization at the glenohumeral joint during the overhead swing motions used in volleyball. It is often the site of muscle damage in athletes who compete in overhead athletic activities and is easily accessible for evaluation using diagnostic ultrasound. Evidence of infraspinatus damage has been observed in subjects after a single bout of eccentric external rotation protocol using an isokinetic dynamometer in a study completed using healthy college age students in 2011 by Oyama et al.[18] With the intensity and volume of swings during pre-season training, volleyball athletes likely experience similar levels of fatigue with overuse, and are appropriate subjects for this method of testing.

The relationship between abnormal scapular mechanics and shoulder dysfunction in athletes has been observed in a number of overhead sports with a greater incidence of shoulder dysfunction found in athletes who have poor scapular mechanics and posture.[6,9,23-26] With a high prevalence of overuse injuries in volleyball the interaction of the scapular and rotator cuff musculature becomes very important during dynamic motion. The musculature of the glenohumeral joint serves to provide a stabilizing force to the humeral head within the glenoid fossa. Several muscles act together to create force couples to stabilize the shoulder and prevent instability. The synergistic motion of the infraspinatus and lower trapezius facilitates normal motion of the scapula on the thorax during external rotation of the shoulder. This is an important force couple as the rotator cuff tendon can become overloaded if the scapular stabilizing muscles do not activate correctly to guide motion of the scapula and maintain the subacromial space.[27,28] Changes in subacromial space can lead to tendinitis, impingement, and rotator cuff tendon strain and rupture. The association between abnormal scapular positioning, glenohumeral motion, and rotator cuff trauma in overhead athletics supports the need to create training programs which train the athlete to improve movement efficiency of the upper extremity which may prevent overuse injury at the shoulder. [15,24,29,30]

Scapular mechanics play an important role in determining the efficiency of motion and transfer of forces at the shoulder girdle during an overhead swing. When the arm is abducted above 90°, the movement of the scapula along the thorax to bring the arm into an overhead position is guided by several stabilizing muscles at the posterior shoulder.[31] Alterations in scapular mechanics is termed scapular dyskinesis, and has been implicated as a factor in shoulder pain and disability in overhead athletics.[29,32-34] The leading complaints of shoulder pain in volleyball include muscle strain, impingement, instability, and posterior shoulder tightness, all of which have been linked to scapular dyskinesis and overuse of the shoulder by the athlete.[5,6,10,11,14,30]

Scapular dyskinesis has been studied heavily in baseball, which has a similar overhead motion in comparison with the volleyball swing with regards to high eccentric loading in external rotation and quick forward acceleration of the arm. [13,18,27,28,35,36] However, there have been few studies that examine scapular dyskinesis in volleyball players, and none that focus on rotator cuff trauma and associated scapular dyskinesis. Therefore, the purpose of this study is to identify changes in the infraspinatus CSA and EI following participation in pre-season volleyball training as well as assess the effects of training on scapular mechanics and associated development of trauma in the infraspinatus muscle.

Inefficient scapular motion influences the glenohumeral and scapulothoracic muscles which work to bring the arm up overhead to perform the spiking and serving motions utilized in volleyball. [24-26,30,32,35,37] All rotator cuff muscles have an attachment to the scapula, thus the scapula must be able to elevate properly so that these muscles may act along the correct lines of pull. [24] The coupling mechanics of the rotator cuff with movement of the scapula during the first 90 degrees of abduction is essential for efficient glenohumeral motion.[15,38]

For this reason we hypothesize that scapular dyskinesis in the volleyball athlete may contribute to infraspinatus muscle trauma. Due to the high volume of overhead swings completed during the pre-season, it is expected that infraspinatus CSA will increase due to overuse and resultant muscle damage and edema. We hypothesize that there will be a relationship between scapular dyskinesis, high training volume and muscular damage to the infraspinatus during the pre-season.

Research Questions and Hypotheses:

1) Is there a significant change in CSA and EI of the infraspinatus following pre-season volleyball training?

   We hypothesize that the training volume of pre-season volleyball will lead to a significant increase in CSA and EI of the infraspinatus.

2) Does the severity of scapular dyskinesis change following pre-season volleyball training?

   We hypothesize that the severity of scapular dyskinesis will increase over the course of the pre-season.

3) Is there a relationship between the presence of scapular dyskinesis, training load, and changes in CSA and EI?

   It is also believed that the presence of scapular dyskinesis will correlate with high training load, as well as greater changes in CSA and EI.

CHAPTER II: LITERATURE REVIEW

Incidence of Shoulder Injury in Volleyball

In the sport of volleyball, athletes are subject to repeated loads from jumping and landing as well as from overhead swings and making defensive plays. The variety of movements required to be successful in the sport requires high levels of neuromuscular control, power, and endurance. Injury is an inherent risk of all sports with volleyball ranking as the eighth highest in rates of injury/exposures in youth sports.[39] An athletic exposure is defined as one athlete competing in a single game or practice session.[1,9] Injury in sport is defined as an incident that results in lost time participating in practice or competition by the athlete. Injuries can be classified into two categories: acute and overuse. Acute injuries have a sudden onset with a known cause, while overuse injuries develop insidiously over time or as a result of repeated traumas. Overall, the shoulder is the third most frequently reported area of injury in volleyball, following the ankle and the knee, respectively.[1,3] However; the shoulder has the highest rate of overuse injury reported. [1]

Overuse conditions in volleyball are reported at 0.6 injuries for 1000 athletic exposures with the shoulder being most frequently reported area of complaint.[5] Along with being the most frequently reported area for overuse injury it also accounts for the most time loss, reported at an average of 6.2 weeks per injury.[5] Training overload is cited as a leading cause of overuse injury, and with the sudden increase in practice time during the pre-season, athletes often experience increased shoulder pain due to overuse.[6]

The incidence of shoulder injury in volleyball athletes during the preseason has been recorded at 6.5 injuries per 1000 athlete exposures as compared to 2.82 injuries per 1000 athletic exposures during the regular season during a 16 year epidemiological study conducted from 1988-2004 by the NCAA.[1] This study encompassed all divisions of the NCAA and surveyed a large population within the volleyball community that is representative of the sport as a whole. Several authors have reported overall injury rates during over one competitive season at similar rates to that found by the NCAA. Bahr et al.[2] found rates of 3 injuries per 1000 exposures in beach volleyball. Verhagen et al.[5] found rates of injury throughout the season of 2.6 injuries per 1000 exposures. From this data it is apparent that the pre-season is a period of increased risk for injury, due to a sudden increase in activity and heavy training loads. It is estimated that all rates reported do not fully represent injuries sustained as many athletes have injuries that are not yet symptomatic or are not severe enough for the athlete to seek medical attention.[1,2,6,10,11]

Overuse Injuries at the Shoulder

In volleyball, overuse mechanisms rather than acute incidents account for approximately 20-32% of all shoulder injuries sustained in practices and games.[1,5] Overuse injuries lead to chronic pain and inability to perform at the desired level of participation throughout the entirety of a season.[1,2] Early intervention with training programs and awareness of risk factors for injury may help to prevent overuse injuries and increase the longevity of the athlete throughout the season.

Overuse conditions are defined as an inability to tolerate repeated stresses over a period of time, resulting in symptomatic overuse injury.[7,8,40] In sports medicine, overuse injury is categorized into four types; (1) pain in the affected area after physical activity; (2) pain during the activity, without restricting performance; (3) pain during the activity that restricts performance; and (4) chronic, unremitting pain even at rest.[7] Often an athlete will not complain of their pain until it inhibits performance in their chosen activity or affects activities of daily living.[1,6,41]

Injury generally occurs as a result of multiple risk factors that are both intrinsic and extrinsic. Intrinsic factors are non-modifiable and include anatomy, age, sex, and previous injury. Extrinsic factors are modifiable and include training type, volume of training, technique, equipment, and environment.[8] Strains of the shoulder musculature are one of the most commonly seen injury in overhead sports and accounted for 5.2%-10% of volleyball injuries that received medical attention during two prospective epidemiological studies of elite level volleyball athletes.[1,2] Other studies have reported rates of shoulder overuse injury as high as 30% during a season.[10] This high value of injury rate may actually be more realistic as overuse injuries often come on insidiously and do not result in lost time from competition until the problem has become chronic and is causing disability.[13]

The literature cites several possible factors which contribute to overuse injury at the shoulder. The first risk factor is the spiking and serving method used by the athletes.[2,3,12,13] The overhead motion of spiking and serving has several key components that include the arm cocking, arm acceleration, and follow through phases. Between the cocking and acceleration phases there is a critical instance of maximum external rotation of the glenohumeral joint before the arm is brought forward. To attain this position, the infraspinatus is the primary agonist muscle and the teres minor acts as a secondary mover. As the athlete accelerates the arm forward to strike the ball the glenohumeral joint must internally rotate and flex while the elbow extends.[13]

The posterior shoulder musculature must then act to prevent anterior displacement of the humeral head by contracting eccentrically to control the forward motion of the arm.[37] This causes further activation of the infraspinatus and teres minor, leading to fatigue and potential for muscle damage. During the cocking phase of the spike and serve, the athlete experiences 54-71% of maximum voluntary contraction at the rotator cuff musculature which serves to counteract the distractive forces on the humerus, that have been reported as upwards of 80-120% of the athlete's body weight.[17,37] The stresses imposed through repetitive overhead swings can place significant strain on the musculature, which can lead to tissue damage which displays through edema, muscle soreness, and increased CSA of the muscle.

Risk Factors for Shoulder Injury

In the sport of volleyball, there are several types of overhead swings that attackers use to spike the ball: straight ahead, cross court, and the roll shot, which is an off-speed ball hit over the net. Each of these swings requires a significant force to be generated through the trunk to the upper extremity to contact the ball with a high velocity. Of these methods the roll shot requires the least amount of force.[13] Reeser et al.[13] did not find a statistical difference between the straight ahead and cross court spikes with respect to joint position during kinematic analysis throughout the swing. However; a study by Mitchinson et al.[12] found that the trunk and upper arm positions did have an altered position at impact, with the arm forward of the trunk due to rotation of the trunk during the swing. The authors believe that increased axial rotation of the trunk during a cross court shot places increased stress on the shoulder during follow through which increases risk of injury compared to a straight ahead or roll shot spike. The forward position of the shoulder increases the eccentric load on the posterior shoulder muscles. The positions which hit more cross court shots are the outside and right side attackers. Outside attackers have the highest rates of injury (37%) of all positions.[4]

Serving style has also been attributed to a difference in shoulder injury prevalence. Athletes who perform a jump serve are more likely to experience shoulder pain than the athlete who performs a standing serve.[6] This difference is likely due to the increased force generated by the trunk and legs during the jumping approach as compared to a stationary service method. Mechanically the jump serve is similar in motion to an overhead spiking motion, while the standing serve generally requires less external rotation of the shoulder when the arm is brought overhead. The forces are transferred along the kinetic chain to the glenohumeral joint. The forces cause a distractive mechanism which must be resisted by contractions of the rotator cuff muscles.[37]

Muscle Recruitment Patterns During Overhead Motion

Balance between the internal rotator muscles which work to accelerate the arm forward as the athlete goes to strike the ball and the external rotators which serve to decelerate the arm during follow through is important to dynamic stabilization of the shoulder.[42] The highest peak muscle activity for the internal rotator muscles (subscapularis, teres major, pectoralis major, latissimus dorsi) is seen during the acceleration phase.[37] The infraspinatus and supraspinatus muscles are most active during the deceleration phase of the spiking and serving motion after the athlete has made contact with the ball and is controlling the forward momentum of the arm (37% and 45% MVIC respectively)[17] as well as during the critical instant of external rotation. With the extreme ranges of external rotation available to volleyball attackers must have strong posterior shoulder musculature with sufficient endurance to avoid injury associated with repeated overhead activity During EMG analysis the serve generated the highest peak EMG readings for the infraspinatus and supraspinatus during the deceleration phase.[37] The authors noted a strong similarity between the forces applied to the shoulder in volleyball and that seen in baseball pitching which demonstrates a high prevalence of shoulder overuse injuries as well.[37]

The rate of shoulder pain in attacking positions (middle blockers, outside hitters, and opposite hitters) has been reported at 64%, compared to defensive specialists at 49%.[6] This difference is expected as the attacking positions perform a much higher number of overhead swings compared to defensive specialists.[6] Practicing 16-20 hours a week can result in approximately 40,000 swings during a season for an attacker.[11] When paired with dysfunctional mechanics, swing volume may contribute to the development of an overuse injury.[14]

Scapular Dyskinesis

A second factor that contributes to shoulder pain in overhead athletes is scapular dyskinesis. Scapular dyskinesis is defined as an alteration in scapular movement patterns during arm motion. It has been shown that the presence of scapular dyskinesis can lead to shoulder problems including sub-acromial impingement, instability, and damage to the rotator cuff tendons.[6,14,15,24-26,30,32,35,41,43,44] It can be assessed through visual observation of the scapula during upper extremity motion either digitally or by a trained clinician. Both methods have been validated and are comparable in identification of dyskinesis in the overhead athlete.[1,33,34,45,46] In the sport of volleyball, scapular dyskinesis has been identified as risk factor for developing shoulder pain and disability in performing overhead motion in the sport.

Scapular dyskinesis contributes to poor kinematics at the glenohumeral and scapulothoracic joints, leading to pain and disability during the overhead athletic movements.[6,14,25,29,32,34,37,38] When the arm is abducted beyond 90 degrees the scapular stabilizing muscles must coordinate the gliding motion of the scapula on the thoracic wall to bring the arm overhead in a smooth arc pattern.[25,26,31,32] This pattern allows elevation of the acromion, and prevents impingement of the supraspinatus tendon and long head of the biceps tendon which run in the subacromial space. Normal scapulohumeral rhythm is defined as having the coordination and timing of these two joints during shoulder elevation, followed by smooth upward rotation during glenohumeral abduction and flexion, and finally, downward rotation during humeral adduction and extension. No evidence of winging is present.[33]

Scapular dyskinesis has been described to include scapular winging, side to side asymmetry, and prominence of the medial scapula border.[33,34] Several types of grading systems have been developed to describe dyskinesis based on bony landmark prominences or movement plane asymmetry.[25,29] The current study will utilize the methods employed by McClure and Tate[33,34] which has been validated to identify scapular dyskinesis.

Scapular Dyskinesis in the Overhead Athlete

Overhead athletes show increased presence of scapular dyskinesis in comparison to non-overhead athletes.[35] The literature has also shown that this change in scapular kinematics tends to occur over time with repeated overhead activity.[47] It is unclear whether or not the dyskinesis leads to shoulder pain or if the shoulder pain causes an adaptation in muscle activation patterns which predisposes overhead athletes to developing dyskinesis. These athletes may or may not present with symptomatic shoulder pain during initial evaluation; however, an increase in prevalence of shoulder pain is correlated with patients with scapular dyskinesis.[6,10,14,24-26,30,32,33,35,43,44,48,49]

There are several possible factors which lead to scapular dyskinesis, including changes in the activation of the scapular stabilizing muscles, damage to the neurological structures which innervate these muscles, and reduced length of the pectoralis minor muscle.[33] Innervation for the scapulothoracic muscles comes from the long thoracic, dorsal scapular, and spinal accessory nerves.[33] Proper neuromuscular function of the scapula assists in maintaining muscle length tension relationships between the scapulothoracic and glenohumeral musculature that create smooth movement patterns and efficient transfer of forces during overhead activity. Correct motion between these joints assists in maintaining the glenohumeral and subacromial joint spaces during overhead activity.[46] When this space is decreased due to swelling or mechanical obstruction the athlete often experiences subacromial impingement syndrome that can lead to muscular damage to the rotator cuff and degeneration of the tissue over time.[25,26,45] Other complications from scapular dyskinesis include muscle imbalance, single sided dominance, and body alignment problems, which can in turn make the athlete more prone to injury or worsening of the condition.[29,32,33]

Despite many of injuries associated with scapular dyskinesis, athletes who present with scapular dyskinesis are not always symptomatic; many individuals maintain the ability to function normally in their daily lives and in athletic competition. When completing an evaluation for pain in the upper extremity the clinician should observe for dyskinesis and determine if it may be a factor in the injury or condition assess scapular movement patterns and determine if a dyskinetic pattern is present.[29,32] In the sport of volleyball the presence of dyskinesis should be taken seriously, as the athlete may develop symptoms as the volume of training increases from what the athlete has experienced previously in his or her career. Changes in the athlete's playing position may also effect the volume of overhead swings taken by the athlete during a season.

Measuring Scapular Dyskinesis

Measuring scapular motion can be completed through video analysis, 3-D motion assessment or clinical real-time observation. 3-D motion assessment is completed by attaching reflective markers directly on the skin above the bony landmarks of the scapula and analyzing the motion through electromagnetic imaging. This method is time consuming, and would not be indicated for the population being studied in this project, or for clinical practice.[46] For this reason the majority of research cited is based on video analysis and clinical observation validity for identifying scapular dyskinesis. Clinical observation of scapular motion has been shown to be valid and reliable through comparison to 3-D motion assessment. A moderate inter-rater reliability was found when trained clinicians viewed video of an athlete performing the test motions, K_w=.57.[33] This method of assessment is a tool that can be used in sports medicine settings to evaluate altered scapular movement patterns without the time consuming and expensive method of 3-D motion analysis.[29,33,34]

Visual observation of the shoulder/scapula by a trained clinician has been validated as an appropriate method for determining the extent of dyskinesis, and can be used to determine the most appropriate intervention to correct dyskinetic motion patterns.[33,46] In the validation study, motion was assessed through bilateral active shoulder flexion and abduction in a weighted position while the patient is viewed from a posterior angle.[33] The participants were then assessed through a 3-D motion analysis which reflected the findings of the clinicians; those participants with observed dyskinesis possess different kinematics which include scapular upward rotation, posterior tilting and external rotation, and clavicular retraction and elevation when the arm is raised overhead.[34] The rating system for video observation describes scapular motion patterns as normal, subtle dyskinesis, and obvious dyskinesis.[33]

Infraspinatus activation and scapular motion patterns

The infraspinatus and teres minor are highly active during external rotation, which occurs as part of the arm cocking phase during the spike and serve.[37] As the athlete fatigues, these muscles lose the ability to externally rotate the shoulder at the same magnitude to maintain the force that can be applied to the ball when spiking or serving.[36] Poor neuromuscular control, as a result of fatigue at the shoulder girdle may lead to or perpetuate many common shoulder overuse injuries including, subacromial impingement, rotator cuff tears, and glenohumeral instability.[35,36,50] As the activity in the infraspinatus increases the scapular stabilizing muscles (lower trapezius, serratus anterior) fatigue which leads to an upward rotation of the scapula and altered shoulder kinematics.[27,28] An important force couple relationship exists between the lower trapezius and infraspinatus; in this interaction the lower trapezius functions to maintain scapular contact with the thorax while the infraspinatus performs external rotation of the shoulder.[27,28] Maintaining muscular balance between the scapulothoracic and glenohumeral muscles is important in prevention of poor mechanics which may lead to overuse injury pathologies.[35,41]

Overuse pathologies

During the volleyball pre-season the athletes often participate in two practices a day, along with strength and conditioning workouts. During this time the athlete is subject to much higher intensity loads than their body is used to experiencing. The result of this increased physical activity is muscle soreness and fatigue. Muscle tissue has the ability to adapt to sudden changes in activity levels by breaking down and rebuilding over a relatively short period of time, allowing strength gains. The literature has shown that a single bout of high intensity eccentric exercise which initiates delayed onset muscle soreness (DOMS) symptoms provides a protective effect against future high intensity exercise bouts.[16,19,51-53] The protective effect has been thought to be due to a repair of micro-tearing of the weakest muscle tissues which occurs as a result of eccentric exercise. The muscle is then re-built stronger so that it may tolerate a similar intensity of exercise in subsequent repetitions of the same motion.[16] During the pre-season, the athlete experiences these effects during the first practices; however, without sufficient time for recovery and synthesis of new muscle fibers the athlete can experience muscle soreness and fatigue for the duration of pre-season training without the protective benefits and building of new muscle fibers.

Oyama et al.[18] demonstrated that the adaptive changes in the CSA of the infraspinatus muscle can be used as an indicator of overall shoulder girdle inflammation and damage. A significant increase in infraspinatus CSA, following eccentric external rotation protocols has been observed in work with healthy college students.[18] Due to similar overhead motion required for a volleyball spike we hypothesize that a comparable increase in CSA would be found in volleyball players. In volleyball, there is no limit on the number of swings an athlete may perform in any given practice or competition. Unlike baseball pitchers, volleyball players do not have a designated time for recovery between heavy bouts of overhead swings. Therefore, we could expect that over the course of a pre-season training camp, volleyball players would sustain trauma to the infraspinatus similar to that seen in other overhead sports.

Effects of Fatigue on Muscle Tissue

Through panoramic ultrasound measurement of the shoulder the quality of the muscle tissue can be assessed through echo-intensity (EI).[54-58] EI is measured by assessing the grey scale quality of each pixel within a specified area of the ultrasound image. Decreased values on the grey scale indicate improved quality of the muscle tissue.[54] The scale depicts a number between 0 and 255.This method of determining muscle quality has been validated through comparison of panoramic ultrasound to single transverse measurements.[55] It has been demonstrated in previous works that presence of intramuscular fat content and fibrous tissue decreases the muscle quality and negatively influences the power generation of the muscle during activity.[59] In the short term, measurement of EI would not show an increase in fatty infiltration, but rather would show changes in echo intensity due to infiltration of swelling and metabolites in the muscle.Young individuals have a significantly lower EI than elderly counterparts due to muscle loss and increased adipose tissue gain which occurs with aging.[60,61] Thus for comparison of data between individuals in the current study it is important that subjects are within a similar age range. Changes in muscle quality are influenced by release of chemicals and buildup of fibrous tissue from micro-trauma and overuse. During a pre-season training period, the effects of delayed onset muscle soreness (DOMS) and repetitive motions causing fatigue are likely to elicit these changes and influence the EI observed in diagnostic ultrasound.[16,51-53]

The speed of muscular contraction required for volleyball is quick as the athlete must be able to perform explosive motions (jumping, spiking, serving etc.) to be successful on the court. A linear relationship exists between speed of contraction and muscle damage with repetitive contractions at a high velocity. Chapman et al.[19] found that there was a 450% increase in peak creatine kinase (CK) levels following a bout of fast velocity contractions as compared to slow velocity contractions. CK levels indicate damage to the muscle tissue as it is released when muscle tissue breaks down. Subjectively, the participants experienced an increase in DOMS symptoms after the fast velocity exercise bout compared to slow velocity training.[19] This data is supported by Shepstone et al.[62] who found that repeated bouts of high velocity isokinetic exercise lead to an increase in muscular CSA and increased muscle protein remodeling due to micro-trauma sustained in the tested muscle group. Over the course of the pre-season levels of CK are likely to increase, as muscle does not have sufficient time to recover from the repetitive loading that occurs during training. These factors and infiltration of muscle proteins due to damage can be observed through changes in the EI of the muscle. In addition, CSA of the muscle assists in assessment of muscle condition by tracking changes of muscle volume due to atrophy, hypertrophy, disease, and injury.[63-66]

Ultrasound measurement of Cross-sectional Area

The use of ultrasound technique to identify abnormalities in the musculature of the shoulder has been validated and is a useful tool in diagnosis of musculoskeletal muscle damage and quantification of cross-sectional area.[63-65,67-69] Ultrasound measurement of muscle CSA has been validated against MRI arthrogram, which is considered the gold standard in musculoskeletal diagnoses.[64,65,67,69,70] The reliability and validity of panoramic ultrasound gives clinicians another tool to use which may assist in diagnosis of injury and identification of physiologic changes in the muscle tissue due to overuse training, or injury.[63-65] Benefits of ultrasound measurements over MRI include the ease of use in clinic, low cost, no exposure to radiation, and availability. Ultrasound is a relatively inexpensive and efficient method of determining changes to the muscle and has been verified with 92.3% sensitivity and 94.4% specificity for full-thickness and 66.7% sensitivity and 93.5% specificity for partial-thickness tears.[20-22]

The infraspinatus is one of the four rotator cuff muscles which functions to stabilize and control motion at the glenohumeral joint. The infraspinatus has a larger CSA than the supraspinatus or teres minor which perform similar function as the infraspinatus.[18] The average width of the infraspinatus tendon is about 22mm, compared to 20mm for the supraspinatus, and inserts into the entire middle facet of the greater tuberosity.[21] In previous studies the infraspinatus has been used as a marker of overall damage to the shoulder due its location and ease of measurement via diagnostic ultrasound. Prior studies have shown that US measurement is a reliable method of determining infraspinatus CSA and EI, CSA reliability in a previously conducted study showed US can be used to measure muscle area with good reliability, ($ICC_{2,1}$ =.984).[18] Primarily US imaging to evaluate EI is completed to measure fatty infiltration indicating a decrease in muscle quality however in the case of short term muscle damage it can be used to assess the infiltration of swelling, metabolites, and other biologic material within the muscle.

The infraspinatus has been recorded to have a mean thickness of 4.4mm in healthy female subjects through diagnostic ultrasound imaging. This measurement is similar to the thickness of the other rotator cuff muscles, supraspinatus (4.9mm), and subscapularis (3.8mm).[71] These researchers did not find any significant difference between the muscular width and thickness of the infraspinatus of the dominant and non-dominant arm in their subjects.[71] For the current study the measurements of infraspinatus CSA and EI were taken bilaterally prior to the pre-season and at the end of pre-season training.

CHAPTER III: METHODS

Participants

Seventeen NCAA division I varsity female volleyball players participated in the current study which took place during the pre-season training period for the 2015 NCAA Division I volleyball season. All participants were between the ages of 18-21 years old and were registered as student-athletes at the University of North Carolina at Chapel Hill for the 2015 fall semester. This group consisted of two setters, three defensive specialists, and twelve athletes who played attacking positions. There were three right side players, four middle hitters, five outside hitters. Complete participant demographics appear in Table 1. Inclusion criteria for the current study included membership on the varsity volleyball team at the University of North Carolina at Chapel Hill for the 2015 season, and ability to complete all testing sessions. Exclusion criteria for the current study included inability to participate in pre-season training, or testing sessions due to current injury or illness. All participants completed a health history questionnaire, underwent pre-participation screening for the upcoming season, and signed an informed consent document approved by the University of North Carolina at Chapel Hill Institutional Review Board.

Height (cm)	Mass (kg)	Age (years)	Limb Dominance	Position	Volleyball Experience (Years)
170.14±9.87	77.09±8.68	19.71± 1.16	n=17 Right n=0 Left	2 setters 3- DS/Libero 12-Hitter/Blocker	7.82± 2.24

Table 1. Participant Demographics

Instrumentation and Set Up

A single video camera (Casio Computer Co., Ltd., Tokyo, Japan) was used to record the scapular dyskinesis test, and play back the recorded motions. Video was analyzed by the principal investigator (K.C) to observe for dyskinetic patterns of motion bilaterally. Each shoulder was rated separately and given a score of 0, 1 or 2 to quantify the amount of dyskinesis present. Reliability for the principal investigator was determined for both intra-rater and inter-rater reliability with observation of video of 17 participants. The videos were watched two weeks apart and were graded without viewing previously determined scores during that time period. Time between video grading sessions was determined based on the length of the average pre-season. For the right limb, intra-rater reliability was assessed through ICC. Excellent intra-rater reliability was determined. The principal investigator also was assessed for inter-rater reliability against a trained grader. Kappa coefficients were determined to be substantial with K_{avg} =.853 Results are listed in Table 2.

	Pre Right Scapular Dyskinesis Tests	Pre Left Scapular Dyskinesis Test	Post Right Scapular Dyskinesis Test	Post Left Scapular Dyskinesis Test
Inter-rater reliability (K)	.809	.815	.884	.906
Intra-rater reliability (ICC)	.822	.969	.895	.969

Table 2. Scapular Dyskinesis Test Statistics: Inter-rater and Intra-rater reliability

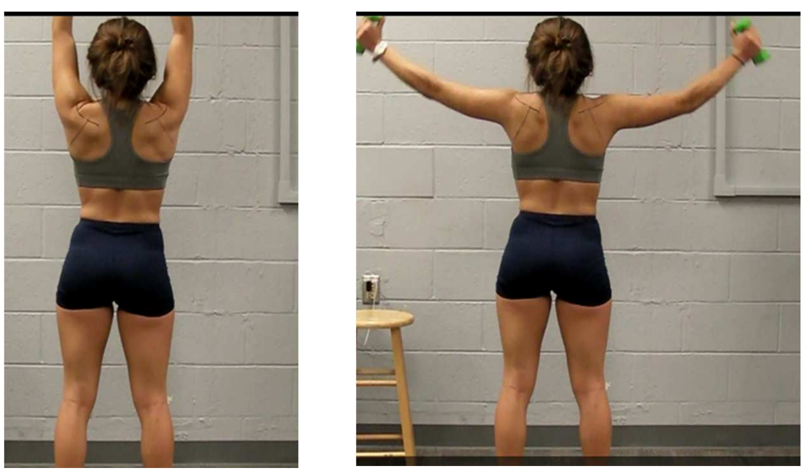
Similar to scapular dyskinesis, three images of the infraspinatus were collected bilaterally and saved for analysis of CSA and EI after all testing was completed. A pilot testing session with the principal investigator (K.C.) was completed with 11 participants to establish repeatability and precision of the investigator of measuring the infraspinatus. Excellent intersession reliability and precision was established for measurement of the CSA for the right (ICC=.974) and left (ICC=.937) infraspinatus respectively. Excellent intersession reliability and precision was also established for EI on the right shoulder (ICC= .934), while a poor reliability and precision was established for the left shoulder (ICC=.500). The principal investigator collected all images during data collection to ensure reliability and precision across all measurements and all subjects.

Right CSA	Left CSA	Right EI	Left EI
.974	.937	.934	.500

Table 3. ICC for CSA and EI: Intra-rater reliability

Procedures

Prior to data collection all participants signed an informed consent approved by the IRB at the institution and were educated on the objectives of the project. Data collection sessions for assessment of scapular kinematics as well as panoramic ultrasound measurements occurred prior to the start of pre-season practice as well as after the conclusion of the pre-season. Measurements were taken with the participant at a resting state 24 hours prior to the start of pre-season training, and 24 hours after the conclusion of pre-season training. During testing, each participant performed the scapular dyskinesis test and was recorded using a portable video camera mounted on a stationary tripod. Participants were asked to stand facing a blank wall away from the camera, and were videotaped from a posterior view (Figure 1). Adjustments were made to the camera lens between participants to ensure that the view captured the participant from the head to the waist throughout the entire motion and the camera was level at the time of filming. Instructions for the motions performed are described in the section below entitled Scapular Dyskinesis Test.



*forward flexion * abduction

Figure 1. Scapular Dyskinesis Test positions

Panoramic ultrasound measurements were taken by a trained investigator (K.C) for all participants during both measurement sessions to ensure reliability and accuracy of the image obtained. Panoramic ultrasound of the infraspinatus of both upper limbs were taken 24 hours prior to the start of the first pre-season training session and 24 hours after the conclusion of the last pre-season training session. Ultrasound measurements were completed prior to testing of scapular dyskinesis to ensure a resting state of the muscle. Description of testing position is described below in section below entitled Ultrasound Measurements.

Volume of swings was assessed daily during the pre-season training period. Each practice session was filmed and viewed by trained investigators at a later date to assess overhead activity volume experienced by the participants. There are four types of overhead motions which occur frequently in volleyball. The first of these motions is blocking, which is defined as two arms up overhead when the participant is attempting to stop the ball from crossing the net after an opponent contact. A second overhead motion which occurs as part of the offensive strategy is tipping which is defined by the participant contacting the ball with one hand and flicking the wrist to change the trajectory of the ball upon contact. A third overhead motion is setting in which the participant contacts the ball with both hands equally overhead. The final and most frequently occurring motion is the overhead swing, which consists of spiking and serving. These motions are classified as a single handed contact with the ball in which the shoulder comes into a position of full external rotation before accelerating forward to make contact with the ball. A strong relationship exists between overhead swings and shoulder pain in volleyball athletes, due to the extreme forces applied to the shoulder joint during this motion.[2,3,6,10] All overhead contacts were counted for the study however, only overhead swings were statistically assessed in this study due to the high forces produced at the glenohumeral joint during these motions. Two investigators collected swing volume data using the definitions described above. Swing volume was used as a co-variate to changes in muscle CSA and EI during statistical analysis.

Position	Swing Volume	N=17
Attack	844.33±97.015	12
Defensive Specialist	580.67±60.962	3
Setter	536.50±47.376	2

Table 4. Overhead Volume by Position Group

Scapular Dyskinesis Test

Participants were instructed to wear a sports bra for screenings to allow observation of the posterior thorax. Screenings were performed using the procedures described by McClure and Tate et al.[33,34] Each participant was videotaped with a single camera from the posterior view and performed five repetitions of both weighted bilateral active shoulder flexion and shoulder abduction (ten total repetitions). Prior to performing the test, participants were instructed on the movement by the examiner and were allowed to practice each movement once if they were unsure of how to complete it. Participants were instructed to keep the arms at the side of the body to start the test, then elevate both simultaneously into flexion completely overhead in the neutral rotation position (thumbs up) over a three second count, then lower back to the starting position over a three second count. Adduction was completed next with the arms resting at the side of the body, the both arms raised with the thumbs pointed up in a neutral rotation into complete abduction overhead. The motion occurred over a three second count up, and a three second count down for five repetitions. Dumbbell weight was selected based on the participant's body weight: participants < 150 lbs. (68.18kg) used 3lb dumbbells, while those weighing > 150 lbs. (68.18 kg) used 5lb dumbbells.[34]

Ultrasound Measurements: CSA & EI

Participants were asked to wear sports bra which allows for access to the posterior shoulder that allows the ultrasound probe head to directly contact the skin overlying the infraspinatus muscle. Participants were asked to lie prone on the examination table with the arms positioned to the participant's sides with the palms of the hands facing up. The borders of the infraspinatus were marked with a permanent pen after palpation of landmarks. The landmarks included the acromial angle, trigonum spinae, and the inferior angle of the scapula. A straight line was marked from the acromial angle to the trigonum spinae using a straight edge ruler. The second line was drawn perpendicularly, using a standard goniometer, and was marked to the length of the inferior angle of the scapula. This line was drawn at 1/3 the distance between the acromial angle and the trigonum spinae on the medial side (Figure 2).

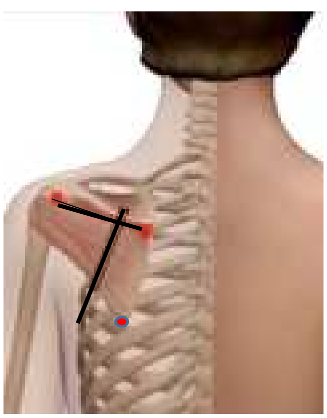


Figure 2. Landmarks for Identification of the Infraspinatus

A custom template was created to fit the ultrasound (US) head and ensure a straight line was followed along the muscle (Figure 3). This template was secured to the patient along the second line drawn using clear tape. The inside of the template was filled with US gel to ensure adequate conduction of the US head. The ultrasound device was consistently set with gain of 60, depth of 5cm, and frequency 12 MHz. Depth of 5 cm was determined based upon pilot testing which determined this to be the depth which would capture the entire muscle in most participants. Three serial images of the infraspinatus were taken bilaterally for each participant during each testing session, by moving the US probe head from a superior to inferior position along the perpendicular line within the template. Images were analyzed using Image J software (National Institutes of Health, Bethesda, MD, USA). The trial means for CSA and EI were calculated and used for analysis of muscle trauma markers including edema, and decreased muscle quality.

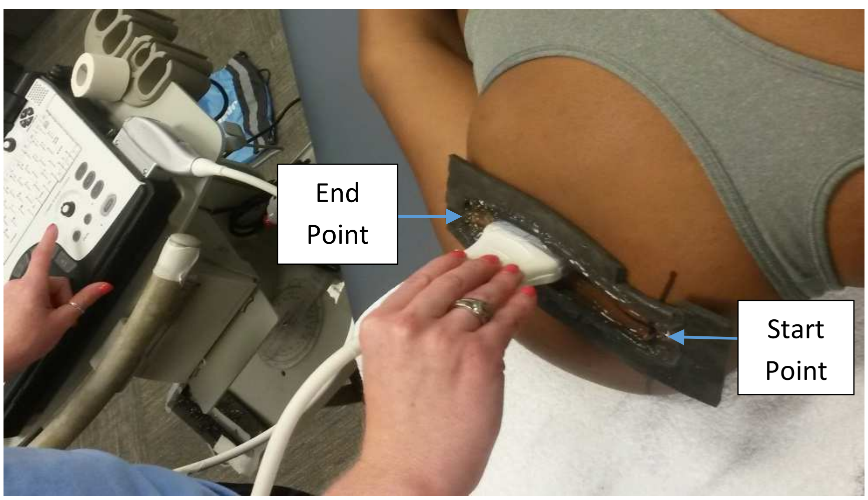


Figure 3. US probe placement

Data Reduction and Analysis

Visual rating of the scapular dyskinesis test was determined at a later viewing time and was rated by the principal investigator on a scale of 0-2. The investigator is a certified athletic trainer who rated the videos for normal motion, subtle dyskinesis, and obvious dyskinesis. Each shoulder was rated separately and given an independent score. Criterion for each category (normal motion, subtle dyskinesis, obvious dyskinesis) are listed in Table 4 and has been shown to be reliable for determining the extent of dyskinesis.[33,34] Each shoulder was rated individually in both flexion and abduction, then the participant was given an overall motion score of normal, subtle or obvious dyskinesis for each shoulder. Operational definitions for normal, subtle dyskinesis, and obvious dyskinesis are outlined in Table 5. For the overall scoring participants was assessed for dysrhythmia and winging in both flexion and abduction separately however the scoring was a combination of these evaluations. A rating of normal on both flexion and abduction gave a normal score. A rating of normal for one motion and subtle for another gave a normal score. Rating of subtle dyskinesis for both motions gave a subtle score, and if either score showed obvious dyskinesis the participant was given a score of obvious dyskinesis.

	Normal Motion	Subtle Dyskinesis	Obvious Dyskinesis
Operational Definition	Both test motions are rated as normal or one of the motions is rated as normal and the other as having subtle abnormality.	Both flexion and abduction are rated as having subtle abnormalities which are not consistently present.	Either flexion or abduction has striking, clearly apparent abnormality, evident on at least 3/5 trials (dysrhythmias or winging of 1 in [2.54 cm] or greater displacement of scapula from thorax)

Table 5. Operational Definitions for Scapular Motion[33]

Analysis of the ultrasound images was completed using Image J software (National Institutes of Health, Bethesda, MD, USA) by tracing the inside border of the epimysium of the infraspinatus using Image J polygon function to assess the CSA. EI measurements were calculated by Image J based upon the color quality (black to white) 0-255, of the pixels within the traced area. One participant was excluded from the data set for this analysis due to severe infraspinatus atrophy on her dominant shoulder which made the image unable to be analyzed. The procedure was repeated for all three images taken for each participant (n=16). Means of the CSA and EI were calculated in Excel to represent the value of CSA and EI for each participant and were used in the statistical analysis.

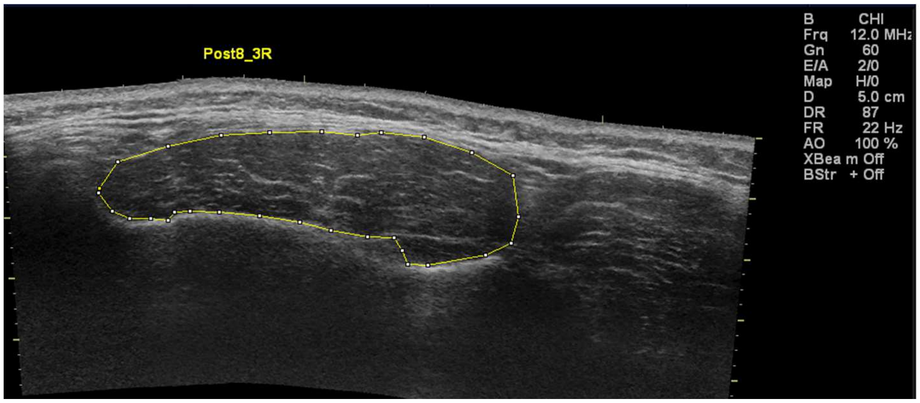


Figure 4: Ultrasound Imaging Analysis

Statistical Analysis

The CSA and EI were assessed using a two-way within-subjects ANCOVA analyses with the swing volume as the covariate variable. Means were compared between the dominant and non-dominant arms and within each limb prior to the pre-season and following the conclusion of the pre-season training period for both CSA and EI of the infraspinatus.

A Wilcoxon Signed Ranks Test was completed to assess changes in scapular dyskinesis severity from baseline testing prior to the start of pre-season, to the end of the pre-season training period.

Spearman's correlation statistic were utilized to examine the relationships between scapular dyskinesis and muscular damage (% change in CSA and EI). Another correlation between the presence of dyskinesis and swing count was run to determine if swing volume may affect the development of dyskinesis over the course of the pre-season. Dyskinesis was set as the categorical variable, while the change in CSA, EI, and swing count were set as the continuous variables during analysis. Statistical significance was determined *a priori* at alpha level < 0.05.

CHAPTER IV: MANUSCRIPT

Background: During the pre-season training period, volleyball athletes experience a high training volume and have little time for recovery. It has been shown that athletes are more likely to develop overuse injuries during the pre-season training period. Forces placed on the shoulder through repetitive overhead activity in volleyball is a risk factor for injury due to the development of muscle damage and changes in scapular kinematics which have been shown to occur with repetitive overhead training.

Hypothesis: We hypothesized that the training volume of pre-season volleyball would lead to a significant increase in CSA and EI of the infraspinatus. We also hypothesized that the severity of scapular dyskinesis would increase over the course of the pre-season training period. Thirdly we hypothesized that the severity of scapular dyskinesis would be associated with high training load, determined via swing count, as well as greater changes in CSA and EI.

Study Design: A descriptive observational study

Methods: 17 female Division One collegiate female volleyball athletes between the ages of 18 and 21 years old (age: 19.71 ±1.16 years old, height 170.14: ± 9.87 cm, mass 77.09 ±8.68kg), who participated in the 2015 volleyball season were recruited for this study. All participants were right hand dominant with 12 athletes playing attacking positions, three defensive specialists, and two setters.

Results: No significant findings were noted for changes in infraspinatus cross sectional area ($F=.036$, $p=.851$) or echo intensity in the dominant limb ($F=.428$ $p=.523$) across the pre-season period. There were also no significant changes in the severity of scapular dyskinesis of the dominant limb across the pre-season period ($z= -.289$ $p=.779$). No significant correlations ($\rho > .05$) between ultrasound measurements (CSA or EI), scapular dyskinesis score, and swing count were found in the dominant limb. Significance was set a *priori* at ($p=.05$).

Conclusions: Pre-season volleyball training volume did not have a significant effect on the development of muscle damage to the infraspinatus muscle. Additionally, there were no significant changes in scapular dyskinesis over the course of this training period. Finally, there was no significant relationship between swing count, indicators of muscular damage and the severity of scapular dyskinesis.

Clinical Relevance: Information from this study provides athletes, coaches, strength and conditioning staff, and athletic trainers with potential risk factors, such as training load and scapular kinematics, for the development of shoulder injury during the pre-season. While no significant findings were made in regards to changes in muscle size and quality, or in the severity of scapular dyskinesis, it is concerning to see such a high prevalence of scapular dyskinesis in this sample of athletes. The prevalence in this sample may be representative of the overall population and would indicates the need for preventative programming to prevent the development of scapular dyskinesis to prevent injury.

INTRODUCTION

Shoulder injury in volleyball is the most common overuse injury in the sport and third most frequently injured area in the whole body.[1-6,10,14,40,42,44] The pre-season training period places significant stress on the shoulder due to high training load and extensive overhead volume experienced by the athletes. During a single volleyball season, greater than 40,000 swings may be taken by a single player.[41] During each swing, the shoulder joint experiences high levels of eccentric demand on the external rotator muscle group as the arm swings forward to strike the ball.[13,16,19,37,72,73] These forces place significant strain at the musculature of the posterior shoulder due to the eccentric forces required to keep the shoulder from distracting during the deceleration phase of the swing. These muscles must also contract to create the necessary external rotation to provide velocity to the ball during the loading phase. In the current study the infraspinatus muscle was selected for study due to the eccentric stress it faces as well as its use as an external rotator. It has been used successfully in prior research also evaluating the effects of repeated loading on muscle damage.[18] Over time, chronic muscle pain and acute muscle damage, including muscle strains, can occur if volume remains high and recovery time is not permitted.

The scapula plays a critical role in coordinated motion of the glenohumeral joint. The rotator cuff musculature of the shoulder functions to provide dynamic support to the relatively unstable glenohumeral joint. Many of the dynamic glenohumeral stabilizers also influence the motion of the scapula due to force couple relationships that facilitate efficient motion at the scapulothoracic and glenohumeral articulations.[25-28,32,37,43,48] A greater incidence of shoulder injury has been found in athletes who have scapular dyskinesis and poor resting posture. The purpose of a scapular dyskinesis assessment is to identify motion patterns which may lead to impingement of soft tissue and promote the development of overuse injuries. Measurement of scapular dyskinesis has been quantified through kinematic analysis as well as visual observation, which is used frequently in clinical practice and has been shown to be equally reliable.[27,29,33,34,46,74]

The combination of scapular dyskinesis and high training load has been suggested as a risk factor for the development of injury to the shoulder joint. Evidence of muscle damage can be identified through ultrasound imaging, specifically by measuring muscular cross sectional area (CSA) and muscle quality through echo intensity (EI). These markers of muscle damage have been shown by Oyama et al (2011) to be reliable outcome measures that indicate damage to the infraspinatus muscle[18]. This ultrasound imagining technique is a cost-effective and time efficient screening solution for the trained clinician to use when monitoring muscle damage in the overhead athlete.[22,57,63-65,67,70,75]

The purpose of our study was to identify changes in the infraspinatus CSA and EI following participation in pre-season volleyball training, as well as to assess the effects of pre-season training on scapular mechanics. We also sought to determine if there was a relationship between, swing count, damage in the infraspinatus muscle, and when scapular dyskinesis. Identification of factors such as training load and scapular dyskinesis is important for the clinician, coach, and athlete to prevent the development of overuse injury during the pre-season which may last into the season and have a negative effect on the performance of the athlete.

METHODS

Participants

Seventeen collegiate female volleyball players (age: 19.71 ±1.16 years old, height 170.14: ± 9.87 cm, mass 77.09 ±8.68kg) who were all right hand dominant participated in this study. Dominant limb was defined as the arm that the athlete strikes the ball with during the overhead swinging motion. Only females were recruited due to the presence of only a female team on campus. Average volleyball experience in this group was 7.82 ±2.24 years of competitive volleyball participation. The cohort consisted of two setters, three defensive specialists and twelve athletes who play an attacking position. The attacking players can further be categorized into four middle hitters, three opposite side hitters, and five outside hitters. Exclusion criterion for the study was an inability to complete the two testing sessions before and after the pre-season training period, as well as missing greater than three practice sessions during the data collection period.

Instrumentation

A single video camera (Casio Computer Co., Ltd., Tokyo, Japan) was used to record the scapular dyskinesis test, and play back the recorded motions. It was placed and leveled on a tripod at a distance from the participant that allowed visualization from the waist up of the participant. The camera was placed so that the upper extremity could be viewed throughout the range of motion. The ultrasound measurements were taken using LogicE software ultrasound device (General Electric, Waukesha, WI, USA) with a 4cm linear array transducer. Settings were standardized for all participants in all trials with a frequency of 12 Hz, Depth 5.0cm and Gain 60. Landmarks for identification of the infraspinatus were determined and a template was secured over the skin. Panoramic images were collected drawing the transducer superiorly to inferiorly along the template placed on the posterior shoulder over the infraspinatus. Images were analyzed using Image J software (Bethesda, MD, USA) for CSA and EI. Reliability and precision of the principal investigator (K.C) was determined for CSA (ICC= 0.974) and EI (ICC= 0.934).

Procedures

Data collection sessions for assessment of scapular kinematics and panoramic ultrasound measurements occurred in a biomechanics laboratory at two time points: 24-hours prior to the start of pre-season training and 24-hours following the conclusion of pre-season training. Prior to testing, each participant was given an informed consent as required by the institutional review board for the university, demographic variables were collected, and participants completed a health history questionnaire.

For the panoramic ultrasound measurements, participants were positioned in a prone lying position with their arms to the side of the body and palms facing upwards. The area for assessment of the infraspinatus was identified through palpation of the trigonum spinae, acromion process, and inferior angle of the scapula. The first line was drawn horizontally from the trigonum spinae to the acromion. A second line, drawn vertically at a 90 degree angle to the first line, was measured 1/3 the distance from the trigonum spinae to the acromion and was drawn to the length of the inferior angle of the scapula. A template which fit the transducer head was secured to the participant along the second line using athletic tape. Three images of both the dominant and non-dominant arm were taken by the same investigator for all trials. The dominant arm was measured first in all cases.

For the scapular dyskinesis test, each participant performed five repetitions of weighted flexion and abduction with the thumbs positioned in a neutral plane (thumbs up). Weights used were based upon body weight, participants < 150 lbs. (68.18 kg) used 3# weights, and those > 150 lbs. (68.18kg) used 5# weights. The testing order for each participant was flexion followed by abduction. For each motion, the participant was instructed to raise their arms through full range of motion at a tempo of three seconds to raise and three seconds to lower. The participants were cued by the clinician to maintain this pace of motion. Five repetitions for each motion were performed. Sufficient inter-rater reliability was determined for the principal investigator through comparison to a trained grader in accordance with the procedures described by McClure and Tate (k=.853).[33,34]

The principal investigator assessed swing count by viewing the practice film captured throughout the pre-season. An overhead swing was defined as a motion in which the shoulder comes into full external rotation and accelerates forward to contact the ball. These motions consisted of the attacking spike and serve. Practice film was viewed at a later date and swings for each participant were tallied by the investigator. All overhead motions including sets and blocks were counted; however, only the total attacking spikes and serves were summed to get a final overhead swing volume (Table 10).

Data Reduction

Analysis of the ultrasound images was completed using Image J software Bethesda, MD, USA). Borders of the target muscle for analysis of CSA was assessed by tracing the inside border of the epimysium of the infraspinatus using Image J polygon function. EI measurements were calculated by Image J based upon the color quality (black to white) 0-255, of the pixels within the traced area. Whiteness in the image, indicated by higher EI values, indicates poor muscle quality due to edema, and fatty infiltration. Each image was scaled in Image J with the reference of one cm prior to evaluation of area to ensure accuracy and precision of measurement. A mean value for the three trials of the CSA and EI was calculated to represent the value of CSA and EI for each participant.

The principal investigator rated scapular dyskinesis on a scale of 0, 1, and 2 indicating normal scapular motion, subtle dyskinesis, or obvious dyskinesis, respectively. Each shoulder was rated separately and given an independent score. Criteria for each category (normal, subtle, and obvious dyskinesis) is listed in Table 5 and was rated separately in flexion and abduction. The overall score given to each participant is a combination of the flexion and abduction scores, and follows the criteria established by McClure & Tate 2009.[33,34] Rating of normal on both flexion and abduction represented a normal score. A rating of normal for either motion and subtle dyskinesis for the other represented a normal score. Rating of subtle dyskinesis for both motions represented a subtle score, and if either motion showed obvious dyskinesis the participant was given a rating of obvious dyskinesis. Measurements were taken at a baseline 24 hours prior to the start of pre-season and 24 hours post pre-season training period.

	Normal Motion	Subtle Dyskinesis	Obvious Dyskinesis
Operational Definition	Both test motions are rated as normal **or** one of the motions is rated as normal and the other as having subtle abnormality.	Both flexion and abduction are rated as having subtle abnormalities which are not consistently present.	Either flexion or abduction has striking, clearly apparent abnormality, evident on at least 3/5 trials (dysrhythmias or winging of 1 in [2.54 cm] or greater displacement of scapula from thorax)

Table 6. Grading Criteria for Scapular Dyskinesis Test

Data Analysis

Comparison between non-dominant and dominant limbs as well as within each limb was conducted between pre-test and post-test measures. Separate between and within subjects repeated measures designs was completed for both CSA and EI using an ANCOVA with the co-variate being swing count. The Wilcoxon signed ranks test was conducted to evaluate changes in scapular dyskinesis ratings from baseline testing to post pre-season training period. Finally Spearman's rho correlations were conducted to evaluate relationships between changes in CSA and EI, scapular dyskinesis scores pre and post pre-season training period, and total swing volume during the pre-season. Statistical analyses were performed using SPSS (Version 23;

SPSS Inc., Chicago, IL). The level of significance was set a priori at alpha < 0.05 for all statistical analyses.

RESULTS

Cross Sectional Area and Echo Intensity

One participant was excluded from analysis of CSA and EI measurements due to severe infraspinatus atrophy of the dominant limb, which was discovered during the initial testing session. This image was viewed by the primary investigator as well as a trained expert who deemed the image unable to be evaluated for accurate muscle size or quality. Images for this participant were taken at each session but were not used in analysis. This participant was asymptomatic for shoulder pain with no history of prior surgery to this limb. For the cohort analyzed, no significant differences were found with changes in CSA when comparing dominant to non-dominant limb across time during the pre-season (F=.036, p=.851). No significant changes in EI were noted between limbs across time (F=.428, p=.523).

n=16	**Dominant Limb**	**Non Dominant Limb**	**Dominant Limb**	**Non-Dominant Limb**
Before Pre-Season			*After pre-season*	
Cross Sectional Area	13.45± 2.21cm^2	12.55±1.69 cm^2	14.11±2.25 cm^2	12.59±2.02 cm^2
Echo Intensity	49.43±9.12	52.23±11.60	48.65±9.17	52.20±10.3

Table 7. Descriptive Statistics: CSA and EI during the pre-season

n=16	**Dominant Limb**	**Non-Dominant Limb**	**F-Statistic**	**p-value**	**Observed Power**
Cross Sectional Area	*+5.7%*	+.30%	.036	.851	.054
Echo Intensity	-1.05%	+1.67%	.428	.523	.094

Table 8: CSA and EI measurement changes

Scapular Dyskinesis

A Wilcoxon signed ranks test was completed to assess the change in scapular dyskinesis over the pre-season. No significant change was found for the group between pre-test and post-test scores for either the dominant or non-dominant limb. In the dominant limb, (z= -.289, p=.773), four participants had improved scores, four participants had decreased scores, and nine participants exhibited no change. In the non-dominant limb there was no significant change within the group (z= 0.00, p=1.00). Two participants had improved scores, two participants had decreased scores and thirteen participants exhibited no change. Scores are displayed in Figure 5.

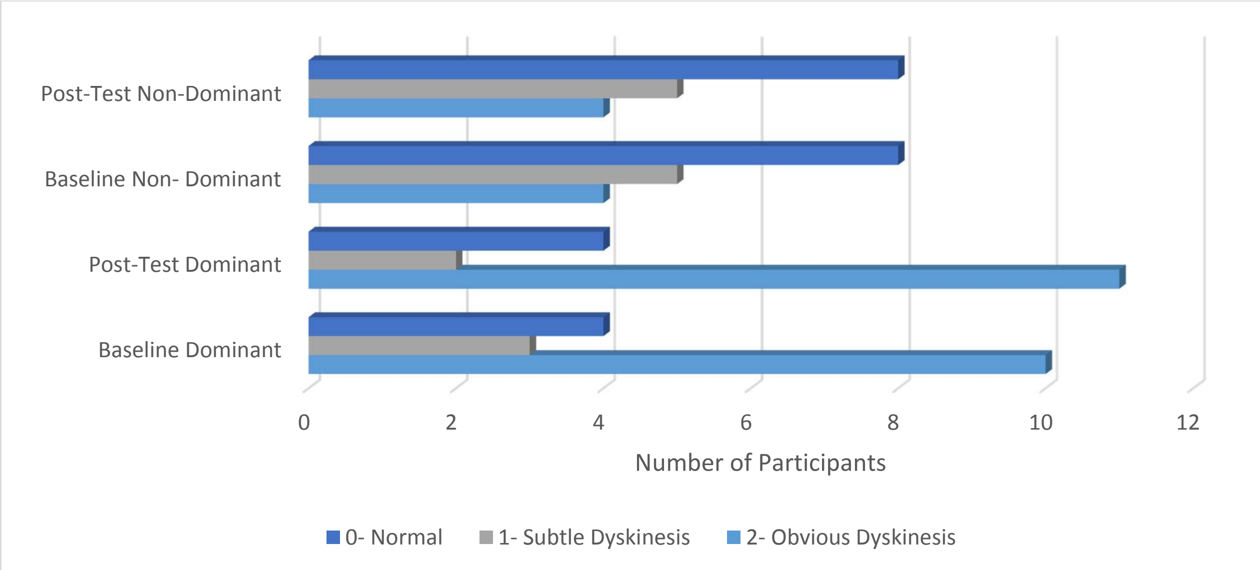


Figure 5. Baseline & Post- Test Scapular Dyskinesis Rank Scores

Relationship between Cross Sectional Area and Echo Intensity and Scapular Dyskinesis

Correlations between the ultrasound measurements and grades of scapular dyskinesis were assessed to evaluate a relationship between scapular dyskinesis and muscle damage. No significant relationships were noted for dominant CSA % change and baseline dyskinesis (ρ=.181, p=.503) or post-test dyskinesis (ρ=.-.328, p=.215). Significant relationships were noted with non-dominant CSA % change and baseline dyskinesis (ρ=.575, p=.020) and post-test dyskinesis (ρ=.533, p=.033) indicating that as CSA increased there was a subsequent increase in scapular dyskinesis rank score. Dominant EI % change and baseline dyskinesis (ρ=-.184, p=.496) showed no significant relationships. Significant relationships were found between non-dominant EI % change and baseline dyskinesis (ρ= -.652, p=.006), dominant EI % change and post-test dyskinesis (ρ= -. 625, p=.010) and non-dominant EI% change and post-test dyskinesis (ρ= -.680, p=.004). The negative associations indicate a decrease in EI value with a subsequent increase in scapular dyskinesis rank score.

n=16	**% Change R_CSA**	**% Change L_CSA**	**%Change R_EI**	**% Change L_EI**
Baseline-RSD Test	ρ=.181, p=.503		ρ=-.184, p=.496	
Post RSD Test	ρ= -.328 p=.215		ρ= -.625, p=.010*	
Baseline LSD Test		ρ=.575, p=.020*		ρ= -.652, p=.006**
Post LSD Test		ρ=.533, p=.033		ρ= -.680, p=.004**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)

Table 9: Correlations between CSA, EI, and Scapular Dyskinesis Test Scores

Swing Count

The amount of overhead training volume was assessed through monitoring of swing count by each participant for serves and spikes. On average the right side hitters had the highest swing count, while the setters had the lowest swing count.

Position	**Swing Volume**	**N=17**
Middle Blocker	853.75±38.248	4
Outside Hitter	801.60±105.254	5
Right Side Hitter	903.00±132.322	3
Defensive Specialist	580.67±60.926	3
Setter	536.50±47.376	2

Table 10. Overhead Volume by Position

Overhead Training Volume

Correlations were also examined between swing count, CSA, EI and scapular dyskinesis test variables. Correlations listed are only for the dominant limb due to all participants being right hand dominant. No significant interactions were noted with the following: dominant CSA % change and swing count (ρ=-.141, p=.602), dominant EI% change and swing count (ρ= -.371, p=.157), and post-test dyskinesis and swing count (ρ=.328 p=.215). Baseline scapular dyskinesis and swing count (ρ=.670 p=.005) showed a significant relationship indicating that those individuals who began with dyskinesis had a higher swing count during the pre-season.

	% Change RCSA	**% Change REI**	**Pre RSD Test**	**Post RSD Test**
Swing Count	ρ=-.141, p=.602	ρ= -.371, p=.157	ρ=.670 p=.005**	ρ=.328 p=.215

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11: Correlations between Swing count CSA, EI, and Dominant Limb Scapular Dyskinesis

DISCUSSION

The purpose of this study was to assess the effects of pre-season volleyball training load on muscle damage, measured through CSA and EI, as well as to explore the potential association of scapular dyskinesis and swing count with these variables in female Division One volleyball athletes. Based on the results of this study, we cannot conclude that the training volume or scapular dyskinesis has a significant effect on muscle damage during this specific pre-season training period. Additionally, we are unable to conclude that there is a significant change in scapular dyskinesis with repeated overhead motion during this training period. No significant relationships were found to exist between CSA and EI, scapular dyskinesis, and swing count during this training period.

The current study showed no significant effect of training load on muscle damage for the dominant limb across the pre-season training period. Studies with a similar design, using diagnostic ultrasound, showed significant muscle damage 24 hours after eccentric exercise was completed [18,52]Our study protocol only took CSA and EI measurement following the completion of the entire pre-season, whereas previous studies took measurements after a single testing session in which the muscle was activated to fatigue. While our data was also taken 24 hours after the completion of activity, the data may not be representative of the cumulative loading of the infraspinatus throughout the pre-season which may account for the differences in findings. Over the course of the two-week training period it is possible that the muscle was able to adapt to the demands placed upon it and therefore evidence of muscular trauma may not have been evident during ultrasound imaging. We believe that had we completed more frequent analyses of the muscle that noticeable changes may have been seen from individual days as opposed to a cumulative loading during the pre-season.

Prior research has noted elevated CSA of the infraspinatus 24 hours post activity with a single external rotation fatigue protocol.[18] However, in our study, the CSA of the infraspinatus was not significantly elevated which may be due to recovery within the time period from the prior day's practice. It should also be noted that the participants in the current study were not required to fatigue the muscle group as in previous studies. The level of activity for each participant was also dependent upon the position of the participant and intensity of practice that day. Therefore we cannot infer expected changes for this population. The cumulative effects that were expected over the two-week training period did not appear in the form of elevated CSA and EI levels. The training load and length of the pre-season may not have been enough to induce significant and lasting changes in the infraspinatus.

The evaluation of scapular mechanics in this study sought to determine if inducing muscle fatigue through a high volume of overhead activity in volleyball would cause a change in the scapular mechanics of the participants. During our study no significant changes were noted after two weeks. This evidence is contrary to that found by Joshi et al.[28] , Ebaugh et al.[27], and Tsai et al.[74]who found external rotation fatigue to have an effect on scapular muscle activation and associated scapular kinematics[27,28,74]. While we believe volleyball activity causes external rotation fatigue it may not have been sufficient to induce visible clinical changes. Our methods utilized for assessing scapular kinematics differed also from previous research that utilized motion capture systems which are able to detect minimal changes in scapular orientation. The clinical assessment test used in the current study cannot detect kinematic changes of that small magnitude. The authors of these previous studies note that the changes observed might not be clinically relevant as kinematics were only altered by a few degrees. The clinical assessment conducted in the current study confirms this finding as no significant changes were observed. Joshi et al.[28] and Ebaugh et al.[27] assessed the scapular mechanics during and immediately after the fatiguing protocol which differed from the current study which evaluated scapular mechanics during a single test 24 hours prior to and 24 hours after the pre-season[27,28].

While no statistically significant changes were noted from the start to the end of pre-season, it is clinically relevant that of the 17 participants, 11 (64.7%) were found to have obvious dyskinesis in their dominant (right) shoulder at the end of pre-season. Scapular dyskinesis has been identified in the literature as a risk factor for developing an overuse injury, and these poor mechanics may lead to a symptomatic shoulder over the course of a season or career.[10,26,32,44] For this reason we recommend that a scapular stabilization program be utilized by volleyball athletes throughout their training to reduce the severity of scapular dyskinesis and minimize risk of upper extremity injury.

It should also be noted that few researchers have looked at the effects of external rotation fatigue protocols on scapular kinematics and the results found in these studies should be viewed as preliminary data in evaluating a relationship between the two variables.[27,28,74] Limited comparisons can be made between the current study and those listed prior as the protocols for external rotation fatigue and methods for evaluating scapular mechanics differed. The current study is the only one to our knowledge that has evaluated the effects of cumulative loading on scapular mechanics in volleyball athletes.

While we did not find any significant changes in muscle size and quality through the US assessment, we believe that the training load may not have been intense enough to elicit lasting damages that could be viewed following pre-season training. The design of the practice plan utilized a combination of heavy swing/jump days and lighter days where the emphasis was placed on defense and footwork. We found an average of 57 swings per session in participants playing attacking positions and 38 in defensive specialists/setters. We also believe that the pain experienced by the participants in the shoulder may be due to damage in muscles not assessed in this study.

No other study found to date has evaluated the relationships between ultrasound measurements of CSA and EI, scapular kinematics, and training volume in overhead athletes. While we did find significant correlations between non-dominant limb CSA, EI and scapular dyskinesis in this sample population, we did note some players who had significant increases in the dominant arm of up to a 25% increase in CSA in two of the athletes who play an attacking position. We also found that there was a statistically significant relationship between swing count and baseline dyskinesis for both the dominant and non-dominant limb. While these findings do not address the primary questions of the current study, as we were looking for changes in dyskinesis, it is interesting to note that those athletes who experienced a greater volume of swings during the pre-season presented with dyskinetic motion prior to training. This relationship may be an indication of adaptive changes over a career as those athletes who ended up with a higher swing count were the same athletes who presented with baseline dyskinetic motion. We believe that the swing count experienced in the pre-season is representative of their overhead volume throughout a season and a career. These athletes should have particular attention paid to them when assessing for dyskinesis as we know that it is an additional risk factor for injury in addition to overuse. We believe that we did not see a significant interaction during post-test measurement because the patterns of dyskinesis did not change significantly.

Epidemiological studies in volleyball players have shown a high prevalence of shoulder damage over the course of the season as well as across a career (Bahr et al.[40], Agel et al.[1], Jadhav et al.[3], Reeser et al.[14]) The results of this study indicate that injury to the shoulder is likely the result of damage over the course of the season as opposed to the two weeks of pre-season in the sample population studied. This is contrary to the results found by the NCAA injury surveillance study from 1988-2004 conducted by Agel et al.[1] However that survey utilized an extremely large sample size and incorporated all levels of competition in collegiate volleyball. Our sample size was much smaller and all athletes were completing upper body strengthening programs over the summer as well as during pre-season; this may have provided a protective effect to the development of shoulder pain and injury. Over the course of two weeks of pre-season training period the participants in attacking positions completed more than 800 swings. The typical regular season consists of 15 weeks of play which could account for upwards of 12,000 swings. This value is lower than that found by Kugler et al.[41] which stated up to 40,000 swings may be completed in a season. The lengths of the seasons, and level of play (professional vs. collegiate) differed between this study and previously reported data. Few studies have looked at total volume of overhead swings, which makes this research important in providing a quantitative examination of the physical demands on an athlete.

One possible explanation for the lack of significance in our results is low power due to a small sample size. Observed power was .054 for CSA and .094 for EI which is extremely low. We chose to exclude one athlete from analysis of cross sectional area and echo intensity due to severe infraspinatus atrophy. Her images could not be read accurately by the investigator due to the poor quality of the image. For this reason our sample size was n=16 for ANCOVA and correlation analyses. We did permit her data to be used in the analysis of scapular dyskinesis changes as she was able to complete the test fully without any restrictions due to pain or weakness, which allowed a sample size of n=17 for that test. The number of subjects utilized in this study is representative of the size of a collegiate volleyball team and therefore was a feasible sample for the purposes of this pilot study.

Based upon previous literature we did not expect a large change in in mean CSA calculated during baseline and 24 hours after the pre-season training in the current study. Oyama et al. showed significant changes in regards to change in CSA with a larger sample size.[18] With a larger sample size, we anticipate that our power would have been higher, thus improving our ability to determine meaningful relationships. Therefore, the results found for volleyball athletes should be used as preliminary evidence and warrants further research into the factors contributing to shoulder injury in volleyball players.

Limitations

There are several limitations to our study that warrant acknowledgement. We were unable to control the activities of the participants outside of the volleyball practice time including team weights/conditioning, as well as outside physical activity. However it should be noted that the participants all completed the same weight training at the same time and physical activity outside of volleyball was likely limited due to the total time spent in training and meetings which took up a significant portion of the day. This study also only looked at the effects of pre-season training on one muscle, the infraspinatus. Strains of the biceps tendon and supraspinatus are common in volleyball and may account for pain and dysfunction among the athletes that was not noted in this study. Additionally, the type of sports bra worn by the participants was not uniform, which may have affected visualization of the scapular border in some participants in comparison to other participants who were able to be viewed more clearly.

Future Directions

Future studies in collegiate volleyball players should evaluate the cumulative effects of overhead swings throughout an entire season. The two weeks evaluated in the current study may not have been long enough to grasp a full picture of the damage to the shoulder that occurs with repetitive overhead motion in volleyball. Daily measurements of the infraspinatus CSA and EI variables may also be valuable to determine damage and recovery on a day-to-day basis. Future investigations should also look at the forces applied to the glenohumeral joint to determine if there is a relationship between the amount of force applied to the ball and development of shoulder damage. The effects of scapular dyskinesis on force production would also be an interesting analysis to complete as the athletes all have different strength capabilities and may be affected by the same training load in different ways due to individual differences. Looking at perceived exertion by the athletes could also be a good indication of the training load, and be useful in guiding training on a day-to-day basis to allow for recovery and prevent injury due to fatigue and overuse. We would also be interested to see what the ANCOVA and Correlation analyses would have been had we only looked at the participants who had a high swing count >800 which would exclude defensive specialists and setters who do not load the glenohumeral joint in the same way as participants who play attacking positions.

Clinical Significance

This research can be used by coaches, athletic trainers and strength and conditioning coaches to guide training loads during the pre-season training period to minimize the effects of cumulative loading on the glenohumeral joint which may lead to injury, and pain. The data shows that a majority of the athletes started the pre-season with some degree of scapular dyskinesis, indicating that it is highly prevalent in the sport of volleyball and may need to be addressed on an overall team basis. We found a correlation between those participants who began with scapular dyskinesis and who had a high swing count indicating these participants with dyskinesis had the tendency to have more overhead volume, likely based on their playing position. It would be recommended in this case to integrate some type of arm care program for the athletes to improve scapular control.

CONCLUSIONS

This research study did not find any significant changes in the CSA or EI of the infraspinatus muscle following pre-season training period. We also did not find a significant change in the degree of scapular dyskinesis present in the participants during the pre-season training period. There were also no significant relationships between CSA, EI, Scapular Dyskinesis, and swing count. These results indicate the intensity of pre-season training is sufficient in conditioning the athletes for the season without inducing significant damaging effects to the shoulder based on the variables assessed in the current study. It would be recommended however that volleyball athletes complete shoulder strengthening and conditioning programs as a component of team training to reduce the prevalence of scapular dyskinesis which was noted in a majority of these athletes. We understand that there is a connection between high training volume, scapular dyskinesis and shoulder injury based on previous literature and the trends observed in the current study. By reducing these risk factors though adequate rest and recovery and decreasing the prevalence of dyskinesis which was present in a majority of the participants in this study we can seek to reduce shoulder injury prevalence in volleyball athletes.

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